PSC of WISCONSIN

Public Service Commission of Wisconsin Office of Energy Innovation
Critical Infrastructure Microgrid and Community Resilience Center Pilot Grant Program

OEI

ATTACHMENT A - COVER SHEET

SECTION I - Provide information summarizing the project proposal.		
Project Title:	Mashkiiziibii Community Resilient Minigrid Study	
PSC Grant Request ($):	**Applicant Cost Share ($):**	**Project Total ($):**
$98,400	$21,306	$119,706
Choose one Eligible Activity		
☐ Critical Infrastructure Microgrid Feasibility Study Level 1 and 2	X Critical Infrastructure Microgrid Feasibility Study Level 3	☐ Community Resilience Center Feasibility Study

SECTION II - Provide information for your organization, signatory, and primary contact for the project.				
Applicant Type:	☐ City	☐ Village	☐ Town	☐ County
X Tribal Nation		☐ Wisconsin Technical College System		
☐ University of Wisconsin System		☐ K-12 School District	☐ 501(c)(3) nonprofit	
☐ Municipal Utility (water, wastewater, electric, natural gas)			☐ Hospital (public or nonprofit)	

Name (on W-9):	Bad River Band of Lake Superior Tribe of Chippewa Indian
Address (on W-9):	72682 Maple St. PO Box 39 Odanah, WI 54861-0039
County or Counties Served by Project:	Ashland
DUNS Number or CAGE Code:	0538069980039
NAICS Code:	921150

Authorized Representative/Signatory (Person authorized to submit applications and sign contracts)		**Primary Contact** (if different from Authorized Representative)
Name:	Michael Wiggins	**Name:** Daniel Wiggins Jr
Title:	Tribal Chairman	**Title:** Air Quality Technician
Phone:	715-682-7111	**Phone:** 715-682-7123
E-mail:	MikeW@badriver-nsn.gov	**E-mail:** Air1@badriver-nsn.gov
Signature of the Authorized Representative	Mike Wiggins	

Bad River Band of Lake Superior Tribe of Chippewa Indian

Mashkiiziibii Community Resilient Minigrid Study

Summary of Project Budget				
Line	**Description**	**PSC Grant Request**	**Applicant Cost Share**	**Total Project Cost**
1	Personnel		$18,455	$18,455
2	Fringe		$2,851	$2,851
3	Equipment			$0
4	Supplies			$0
5	Travel			$0
6	Contractual	$98,400		$98,400
7	Other			$0
8	Indirect			$0
	Totals	$98,400	$21,306	$119,706
	% of Total	**82%**	**18%**	

Applicant Comments: Breakdown of contractual request is found in reference materials Appendix C, SOWs. Breakdown of applicant cost share is found in narrative section 3.4.6 Cost Share. Fringe is calculated at 35.2% of Tribal staff.

Narrative
3.3 Project Description

Introduction
The Bad River Band of the Lake Superior Chippewa is building a clean and resilient future with an advanced renewable energy community microgrid. The band, or tribe, is comprised of 6,945 members on the 124,655- acre Bad River Reservation of mostly undeveloped wilderness, which the community depends on for hunting, fishing, and gathering rights since the *Treaty of 1854*. In 2021 the tribal energy team and partners commissioned the first tribal advanced building microgrids: the Health and Wellness Center, Chief Blackhawk administration building, and Waste Water Treatment Plant. These simultaneous technology pilots are evidence of the team's capacity to plan and execute complex energy projects. However, many lifelines remain vulnerable, such as durable medical devices at the elderly building, perishable food supplies at the IGA supermarket, and resilient backup power for the Head Start preschool. Now a thorough techno-economic study is required to find a feasible path to the larger community microgrid that meets the tribe's clean resilience objectives, given the learnings of the pilot projects. An experienced team comprising of muGrid Analytics, Cheq Bay Renewables, and Madison Solar Consulting are well prepared to support the tribe on this project, as with the previous successful microgrids.

Problem / Motivation
In 2016 a five-hundred-year flood took two lives, halted electric, natural gas and roadways for a week, and caused over $25M in damage. Since then, a series of disaster mitigation and response plans have been completed, which identify resilience objectives and protocols. More recently the tribe identified a phased path towards its clean and resilient energy goals in a *Long-Range Energy Planning Report*. As a result, in 2018 the tribe completed an Emergency Response Plan, an Emergency Evacuation Plan, and a Pre-disaster Mitigation Plan. These documents triaged the worst hazards to the community and identified critical resilience objectives such as cooling shelters and communication systems. Three of the most important buildings identified in these documents have recently commissioned separate microgrids which proved the tribe's capability to plan and execute resilient energy systems. However, the three microgrid buildings can achieve only some of the resilience objectives and for only a small fraction of the population of 1643. Furthermore, the tribe is passionate about clean energy and intends to move quickly towards net zero carbon emissions.

Need
The tribal energy team is investigating a community microgrid for both emergency services and critical infrastructure. Therefore, Bad River is applying for Activity 3, to study expanding its existing building microgrids into a single Level 3 advanced community microgrid of several independently metered Community Resilience Centers. A high-level techno-economic feasibility study is necessary for a microgrid of this scale and scope, because not anticipating significant yet foreseeable barriers could result in millions of dollars poorly invested. For instance, any given battery and solar inverters may not operate with the other distributed energy resources, or an important underground cable could be undersized for peak A/C load.

Study Description

Daniel Wiggins of the Bad River Renewable Energy Team will coordinate and interface with the Tribal council, especially regarding resilience and economic objectives and risk tolerance. muGrid Analytics will perform the majority of technical and economic analysis. The team will request, measure, and model load data using proprietary artificial intelligence tools. Generation and storage adequacy will first be estimated without a distribution model, so that appropriate locations for solar assets can be chosen. The local distribution lines and transformers will be identified and modelled in software, along with a cost model for buying, upgrading, and constructing new infrastructure. Then the lowest cost microgrid topology can be studied in software for safe and secure operation, adding upgrades to lines, transformers, and the interconnection as necessary. The team will evaluate interoperability of equipment, which often requires custom solutions and extra engineering time if chosen poorly. Advanced microgrid controls such as peer-to-peer control will be assessed. Dispatch economics will be studied in the context of the new possible contracts negotiated with Bayfield Electric and Dairyland Power. Madison Solar Consulting and Cheq Bay Renewables will advise on local and state policy, programs and funding opportunities, and engage the utility about possible ownership agreements. Since planning and building the three existing microgrids, all these entities have working relationships with each other, and especially important is the history of cooperation between the Tribe and Bayfield Electric.

The most important findings of the study will reach conclusions regarding:

1. Generation and storage capacities
2. Community microgrid topology
3. Required modernization of the distribution network
4. Identification of interoperable equipment
5. Dispatch algorithm to optimize resilience and economic benefits
6. Cost model to estimate capital expenses
7. Policy regarding customers, Bayfield Electric, and Dairyland Power
8. Legal and business risk of the venture

The specific deliverables of the study will be:

1. *Report*: a comprehensive but concise report of the study assumptions, methodologies, findings, and recommendations (no less than 50 pages)
2. *Microgrid Design*: technical drawings and report sections identifying the most economic distributed energy assets, microgrid topology and interconnection(s), operational tools, and equipment selection – including a single top recommendation given the tribe's objectives
3. *Database*: all load and modelled solar data with instructions and labels
4. *Financial Models*: pro forma and costing tools for future design excursions
5. *Metering*: access and instructions will be provided for the eGauge load meters

Microgrid Description

The study will determine the community microgrid assets and topology without bias, but some features can be anticipated. The HWC building microgrid is already identified as an emergency shelter and will be an important CRC as it already has heating and A/C, medical equipment and staff, and an open community space. A planned HWC expansion could include a gym and additional health services. Additionally, the WWTP building microgrid has solar and storage assets that could be diverted to CRCs for acute needs. The three-phase-branches off the Bayfield Electric feeder make an efficient trunk to distribute power through the microgrid, so a Point of Connection (POC) near there is reasonable. See Appendix A for maps.

3.4.1. [Activities 1 and 2 Only]. Identification of Critical Infrastructure

This grant application is for Activity 3, a Community Resilience Center, Level 3 microgrid.

3.4.2 Key Partners and Stakeholders

Bad River has a well-established team of consultants and stakeholders that are listed in table 1 found in Appendix F:

Letters of support from Bayfield Electric Cooperative, Cheq Bay Renewables and EnTech Solutions are included in the reference materials, Appendix B. EnTech Solutions owns and maintains the three existing microgrids until full tribal ownership is achieved after about six years.

Appendix C contains Scope of Work (SOW) documents for Madison Solar Consulting and muGrid Analytics.

This is the underserved, low-to-no income community that would be affected by this broader microgrid. This is the population that was adversely affected by the 2016 flood and providing essential services, like electricity, would keep people in their homes and not tax other critical infrastructure like the Health and Wellness Center or other community buildings. A map showing the extent of the 2016 flood is found in Appendix A.

The increased resilience resulting from the study would benefit the low income and historically marginalized indigenous community. The focus area includes approximate 130 homes or 25% of the reservation's total housing. The total Bad River reservation population is 1,643[1]. Ashland County's children (<18 years) have nearly a 1 in 4 chance of growing up in poverty (24.2%) which is higher than the US rate as a whole (18.5%)[2]. Of the approximately 516 total households on the reservation, 46% are defined as low-income, very low-income, or extremely low-income[3.] On the reservation, of the population seeking work, there is an approximate 14% unemployment rate[4]. Furthermore, the

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[1] *US Census Bureau. 2015-2019 American Community Survey 5-Year Estimates, https://www.census.gov/tribal/?aianihh=0140*

[2] *United States Census Bureau, Center for Enterprise Dissemination Services and Consumer Innovation, 2019. Ashland County, Wisconsin, https://data.census.gov/cedsci/profile?g=0500000US55003*

[3] *US Census Bureau. 2015-2019 American Community Survey 5-Year Estimates. Bad River Reservation/Employment https://www.census.gov/tribal/?aianihh=0140*

[4] US Census Bureau. 2015-2019 American Community Survey 5-Year Estimates. Bad River Reservation/Income and Benefits https://www.census.gov/tribal/?aianihh=0140

community depends on the preservation of local wilderness and habitats for protected hunting, fishing, and gathering rights, in addition to cultural traditions around respect and stewardship of the land. In Wisconsin climate change will harm the water quality through algal blooms and pollution runoff, disrupt migratory bird patterns, and spread Lyme disease through larger tick populations. A consensus is emerging that pollutants from fossil fuel plants disproportionately affect low-income, minority, and disadvantages communities. The tribe measures ground ozone and PM2.5 and has set its own air quality standards, testament to the high value Bad River places on a clean environment.

The U.S. EPA has documented effects of climate change and how it might affect Northern Wisconsin and the Great Lakes region.[5]

3.4.3 Project Resilience Objectives and Metrics

Resilience encompasses many aspects such as prevention, flexibility in response, and training, which are addressed in emergency preparedness and response plans. But an important requirement of resilience services is energy, which is typically supplied by the electric utility, distributed renewables, natural gas utility, and stored liquid fuels. Some of these energy forms are more or less fungible from the perspective of the service, for instance a dual fuel generator or plug-in hybrid car. Microgrids are characterized by limited available energy resources, and are often a mix of electric, thermal, and chemical systems, so attention should be paid to the resilience, economic, and environmental goals, and the sources of energy chosen.

Developing the most economic microgrid to meet any given resilience objectives can be difficult, especially since many communities don't yet have firm or comprehensive objectives. Fortunately, the Bad River Tribe has already invested an enormous effort in understanding its exposure to climatic and other hazards, and the necessary mitigation and response strategies.

Objectives

The Bad River Tribe leadership has in place a *Pre-Disaster Mitigation Plan* and *Emergency Response Plan*, which includes analysis of the hazards posing the most risk to the community. Depending on the emergency, residents and guests could be asked to shelter in place, seek designated shelter if needed, or even evacuate the reservation. Hosting evacuees from elsewhere is also considered. The hazards related to electric grid outages are tabulated in Table 2 found in Appendix F. All of these objectives can be provided with the utility grid online except non-electric transportation. Therefore, the main microgrid resilience goal is energy to provide services.

Metrics

Conventional *backup power* requirements are simply measured in hours. For instance, NFPA 70 for health centers assumes a constant building load for a maximum outage of several or possibly a few dozen hours. For the most common grid outages this is adequate and can be supplied by generator and

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[5] https://19january2017snapshot.epa.gov/sites/production/files/2016-09/documents/climate-change-wi.pdf

liquid fuel storage, but for the hazards listed in Table 2 (Appendix F) it is not adequate. By comparison, a resilient microgrid with renewable distributed energy can have the following features:

- Guaranteed backup power for short durations
- Stochastic backup power for medium and long durations
- Automatic load shedding in case of higher-than-expected load
- Benefits of aggregated load and distributed generation and storage
- A self-healing micro-distribution network
- Revenue generating possibilities

The performance of a microgrid at providing backup power can be measured by how often it serves (or doesn't serve) the total user load. Regulators reward and penalize utilities based on performance metrics like Customer Average Interruption Frequency Index (CAIFI), but these metrics usually assume multiple interruptions and many customers to calculate an average. With an islanded microgrid we only have one customer and we're certain there will *eventually* be an interruption (if the grid is out long enough), but we hope to delay that as long as possible. Instead, the table below introduces a few novel measures of microgrid performance developed by muGrid Analytics.

Metric	**Units**	**Examples**
Time to first failure (TTFF)	h	A storm outage begins at 4 am and the battery supplies the load until 6 am when it fails due to being empty. The TTFF is 2 h. At 8 am solar produces enough to serve the load until 9 am when the grid comes online, but neither change the TTFF for this outage.
Cumulative operating time (COT)	h	A storm outage begins at 4 am and the battery supplies the load until 6 am. At 8 am the solar produces enough to serve the load until 9 am when the grid comes online. The COT is 3 h.
Confidence in TTFF of x (cTTFF)	%	If a heat wave outage begins, randomly, at any hour of the year, there is a 98% chance that the TTFF will be greater than 2 h.
Confidence in COT of y (cCOT)	%	If a 12 h long Public Safety Power Shutoff begins, randomly, at any hour of the year, there is a 82% chance the COT will be greater than 6 h.
Mean Absolute Error (MAE) of temperature	ºF	A heat wave outage begins at 11 am. The microgrid electric supply and cooling shelter's thermal storage keep the temperature at the desired 75 ºF until 2 pm. From then until 5 pm however, the temperature rises to 80 ºF. At 5pm the temperature returns to 75 ºF. The MAE is 2.5 ºF

The microgrid features of load shedding and aggregation can be measured by how they increase the metrics in the above table. Network self-healing also will improve these metrics, but is difficult to model because it depends on the type of fault and recloser switch operation. Revenue generation and economic performance are calculated many ways, such as Simple Payback Time (SPT), Net Present Value (NPV) and Internal Rate of Return (IRR).

3.4.4 Evaluation of Site-specific information

The site under study is the Bad River Tribe community based off of Maple St. in Odanah, WI. Because of the benefits of a Community Resilience Center Level 3 microgrid, all buildings that could plausibly island on one or multiple Bayfield distribution branches fed by Bayfield Electric Coop distribution branches will be considered. The branches connect to the same radial feeder (east circuit) of the Ashland substation, 14.8 miles driving distance to the west.

The most effective buildings for providing community resilience services are likely the Health and Wellness Center (clinic), Bad River Lodge and Casino, and Elderly Center, which are all on one three phrase branch. Also very important is the administration building, which is on a separate three-phase branch. The table below shows the relationships between community resilience services and centers.

Community Resilience Service	**Relevant Tribal Buildings to Become CRCs**	**Energy Requirement**	**Resilience Metric**
Emergency heating and cooling	clinic, administration, elderly center, preschool, lodge and casino	electric, possibly biomass, thermal (storage)	cCOT, or temperature MAE if thermal modeling is included
Refrigeration of temperature-sensitive consumables (medications, vaccines, milk for nursing)	clinic, lodge and casino, preschool	electric, thermal (storage)	cCOT, or temperature MAE if thermal modeling is included
Durable medical equipment	clinic, elderly center	electric	cTTFF
Communication, rescue, and organizational equipment	administration	electric	cTTFF

The study will then narrow down which buildings, energy assets, and portions of distribution infrastructure most economically achieve the resilience objectives. The constraints and opportunities of each building must be explored and considered in the wider microgrid. A summary of buildings including constraints and opportunities is found in Appendix F, Table 3, however the feasibility study might identify other critical buildings.

Appendix A contains 1) a site map overview of the Bad River Reservation showing the incoming BEC feeder line and focus area. 2) a breakdown of this overview map into three focused sections: East, Center and West. The focus area has two primary restraints: low wetlands and forest cover. Included in the design will be to avoid wetlands and minimize forest removal, although the tribe has recently cleared several acres for the HWC microgrid so is accustomed to the benefits and drawbacks of clearing land.

Existing Distributed Energy Resources		
Site	**Technology**	**Size**
Administration Building	Solar PV	24.3 kW
Administration Building	Battery Storage	20kW/44kWh
Administration Building	Natural Gas Generator	45 kW
Health & Wellness Center	Solar PV	300 kW DC
Health & Wellness Center	Battery Storage	288 kW / 568 kWh
Health & Wellness Center	Diesel Generator	200 kW 400 gal tank
Waste Water Treatment Plant	Solar PV	200 kW DC
Waste Water Treatment Plant	Battery Storage	216 kW / 435 kWh
Waste Water Treatment Plant	NG Generator	500 kW
Headstart Building	Solar PV	19.2 kW DC
Headstart Building	Natural Gas Generator	35 kW
Bad River Lodge & Casino	Diesel Generator	600 kW 500 gal tank
Moccasin Trail Complex	Natural Gas Generator	45 kW

The tribe's Department of Natural Resources will be the project lead on all permitting. They have successfully completed this task for the existing building microgrids so are familiar with permitting requirements for solar PV and containerized battery storage, however the micro-distribution grid will be new territory. Siting, permitting, and review of infrastructure projects will be minimal for upgrading existing assets and can be substantial especially for new overhead lines. On reservation territory, the tribe may be the main authority having jurisdiction (AHJ), but Federal review may be required on the basis of stability of the Midwest Reliability Organization (MRO). Many permitting concerns will disappear if Bayfield Electric maintains ownership of the network but allows the tribe microgrid to island portions in case of a grid outage.

3.4.5 Technologies under consideration

The Bad River energy team is passionate about moving to net zero carbon emissions alongside its resilience goals. The team has already studied most commercially available clean generation resources, and is piloting three solar PV, battery storage, and internal combustion engine (ICE) generator microgrids. Unfortunately, the wind and micro-hydro resource near the reservation are poor.

- *Solar (both PV and thermal):* Solar usually has zero local emissions, very low lifecycle emissions, technology maturity, and cost effectiveness even in northern Wisconsin.
- *Battery Storage:* Solar PV isn't inherently dispatchable so electric energy storage must be considered. Of the many options lithium ion, lithium iron phosphate, and lead acid chemical storage are the most economical and technologically mature at this scale.
- *Biomass Combined Heat and Power (CHP):* Biomass can also reach low lifecycle emissions, especially if the heat has value, but the tribe is concerned about local air quality and even may not tolerate fairly low emissions. Furthermore, residue or waste cellulose sources may not always provide enough feedstock, and the tribe is concerned about the carbon and ethical issues regarding energy crops.

Additionally, the tribe has existing fossil fuel generators that will remain but won't be considered for new or large generation assets. However, they will be integrated with the microgrid so a discussion of emissions and operating cost is relevant.

- *Natural Gas ICE Generator:* The tribe is aware that a large portion of US national emission reduction is due to cheap natural gas, but doubt remains about the lifecycle emissions of extraction and transport. Transgressions such as ground water pollution from hydraulic fracturing are fundamentally at odds with tribal values. Also utility line gas pressure cannot be guaranteed in many of the identified disaster scenarios, as was the case for a week in the 2016 flood.
- *Diesel ICE Generator*: Although diesel is relatively expensive and polluting compared to natural gas, diesel generators lend to better resilience than line-fed natural gas because the fuel is stored in on-site tanks and can power some vehicles in an emergency. The diesel generator only produces emissions during maintenance runs or a grid outage. Also the power output technical low limit is much lower (typically 30% of maximum) compared to a gaseous fuel ICE generator (50%).

Table 4 in Appendix F illustrates the technologies considered and compares their emissions and levelized cost of electricity.

The tribe has also begun preliminary consideration of a small-scale hydrogen electrolysis pilot. The purpose would be to see if longer-term storage provided by hydrogen might be economically feasible or at what price point would it be feasible.

3.4.6 Cost Match

All stakeholders will donate in-kind time to leverage the economic benefit of the OEI grant. In addition, the Bad River Tribe will provide contingency funds to cover any cost over-runs like the eGauge load meter installations, for example. A summary of the full budget can be found in Attachment B, Budget Sheet.

Stakeholder	Hours	Unit	Amount
Bad River DNR	400	$20.25	$8100
Cheq Bay Renewables	50	$100	$5000
Madison Solar Consulting	18	$110	$1980
muGrid Analytics	15	$225	$3375
Total	483		$18,455

Grant funding is required for this feasibility study because the Bad River tribe doesn't have the capital, and borrowing or seeking investment for a resilience project likely isn't possible because the revenue stream isn't clear. Clean energy projects like efficiency upgrades and solar PV installations have predictable economic benefits that are easily monetized, such as utility bill savings. Along with tax incentives and loan or lease options, energy customers can often invest for decent returns or borrow and still see modest savings. But the economic benefit of resilience projects is harder to predict and monetize. For example, when resilience is finally invoked the cost savings could be realized by FEMA or the National Guard, and instead the tribe will see a less-monetizable but substantial benefit in health and safety. Without grant funding the tribe will have no option to move forward with this feasibility study. However, the team will continue to apply for other implementation grants, and will piecemeal construct small portions of the community microgrid without the handrails of a comprehensive techno-economic study.

3.4.7. Data Collection Plan

For residential or commercial meters there are typically two data sets: monthly billing data and 15-minute interval data. The former is always available and the latter sometimes is. The 15-minute data is always preferable if the accuracy can be verified, since it can be used in quasi-dynamic grid simulations of generation, load, and storage dispatch. When data is not available muGrid Analytics has industry standard capabilities of synthetic data set creation by blending commercial building stock data based on the building type (office, warehouse, etc.). muGrid also has advanced load modeling and forecasting capabilities using statistical analysis of existing data and regression forecasts with neural network machine learning tools.

Fortunately, the tribal energy team has already collected monthly billing and 15-minute interval data from the completed building microgrids and solar impact study (focused Bayfield Electric Coop feeder). And because of the close relationship with the utility meter engineer, 15-minute interval data is accessible to the team that resides on the meters but is not typically made available to customers.

Data Scope	**Monthly Billing Data**	**15-minute Interval Data**
Distribution Feeder		Available request, previously used for solar impact study
Health and Wellness Center (clinic) meter	Actively monitor	Actively monitor
Bad River Lodge and Casino meter	Readily available	Meter data may be available on request
Elderly building meter	Readily available	Meter data may be available on request
Chief Blackbird administration building meter	Actively monitor	Actively monitor
Head Start Center (preschool) meter	Readily available	Meter data may be available on request

Given the experience with this site and utility there should be no problem collecting and modeling data well before the 30 June 2022 end of the grant period.

3.4.8. Systems Sizing Analysis

Project Cost Estimates

The project initial capital expenditure (capex) can be estimated after completing several tasks of the proposed feasibility study. Capex will be driven mostly by the sizes of the adequate DERs and the microgrid distribution network. muGrid Analytics has previously developed costing models for typical DERs and building microgrid equipment, but the distribution infrastructure cost model will need to be developed.

The DER capex results from the DER capacities which must be larger than microgrid peak load. This is the sum of the 15-minute interval load profile of each building on the microgrid, currently unknown for lack of data. The peak load and microgrid topology also determine the required power capacity of different lines and transformers, which might necessitate infrastructure upgrades. More accurately, the DER capacities need to be sized to meet resilience objectives, such as 100% air conditioning load for 48 h TTFF at 95% confidence. The optimal mix of DERs to minimize capex is the result of a tradespace exploration of resilient backup power software simulations.

The microgrid distribution capex is completely unknowable at this point because it depends on the results of negotiations with the utility Bayfield Electric. An agreement could be reached where the POC is somewhere in the Bayfield-owned distribution network, and in a grid outage the islanded microgrid is freely operated by the tribe. Or, the tribe may need to buy lines and transformers downstream of the POC, which could be millions of dollars.

Since the proposed techno-economic feasibility study is an optimization, the specific buildings and loads are not assumed to be known *a priori*, and rather are an intermediate result of the investigation. This approach aims to minimize lifetime cost of resilience, and make the best use of valuable tribe and public funds.

Nearly every modern technology company references machine learning or blockchain technology on its website, but possibly few have fully implemented either or understand when traditional methods still have enormous value. Therefore, it's appropriate to say that computational intelligence methods should be part of microgrid planning and operation activities like modeling and forecasting load, sizing energy assets, and solving the unit commitment problem (when to turn on which energy source). Specific methods include fundamental statistics, traditional timeseries decomposition and regression, so-called "DC power flow" simulations, Mixed Integer Linear Programming (MILP), classification algorithms like K-means clustering, and neural networks and the many derivatives. muGrid Analytics has specific research and implementation experience with each of these methods and more.

Critical Load Definition

The resilience objectives in Table 2, Appendix F conveniently lead directly to the critical electrical loads: air conditioning, heating, refrigeration, building lighting, AM/FM radios, communication radios, TVs, continuous positive airway pressure machines, dialysis machines, oxygen supply, vitals care carts, plug loads for phones, laptops, lights, etc. An assumption to be verified is that for most tribe buildings acting as CRCs, the maximum electrical load would come from an extreme heat hazard. So, in the case of the CRCs, 100% of the measured building load is assumed to be critical until a cooling load study is completed estimating the maximum two-day CDD over 90 ºF. In reality this is a reasonable assumption for solar and storage microgrids because muGrid's resilient microgrid design methodology usually results in extra solar capacity in the summer when extreme heat is expected. Also, in a true extreme heat emergency non-AC load can be shed. In the feasibility study load characterizing and modelling for each hazard type will help refine this point immensely.

Backup Duration

As discussed in *Metrics*, muGrid Analytics has developed resilience performance metrics that improve on the conventional backup duration. Depending on the hazard, TTFF of COT may be more appropriate, and both are more meaningful when the statistical confidence of that value is determined. Even so, developing a target TTFF or COT and confidence is difficult because for extreme hazard scenarios grid outages can be many times longer than the grid outages for which we have data. These events are true black swans in that they are rare, not captured by normal distributions, and have outsized impacts on the community. An important feature of black swan events is that they are almost impossible to predict and can only be hedged against.[6]

One effective method of determining the performance of a microgrid is to educate the community on the microgrid's capabilities and then survey the leadership. For the HWC, WWTP, and administration building microgrids, the tribal energy team agreed that 100% of typical load for a TTFF of one week at

[6] *Taleb, Nassim Nicholas. The black swan: The impact of the highly improbable. Vol. 2. Random house, 2007.*

95% confidence was appropriate. The one-week duration comes from the approximate length of the power outage caused by the 2016 flood, but is also a round number maximum for how long emergency services would take to reach the entire tribal population in many hazard scenarios. For heat hazards the cooling load may be much higher than typical load, as discussed above, and also COT and confidence is a more appropriate metric since during a short microgrid outage, buildings with modest insulation and thermal mass will take hours to reach dangerous temperatures. In this case a COT of 1 week with a higher confidence of 98% may be appropriate. All muGrid resilience metrics assume diesel tank refueling, and line natural gas availability depends on the hazard scenario.

Controls Strategy

Microgrid distribution protection will be fully automated. The various short and open circuit faults can be quickly isolated with programmed “recloser” circuit breakers and off-load switches. The advanced distribution management system (ADMS) may even be able to automatically reconfigure the network topology, however in this case circuit breakers and off-load switches need central and/or peer communication links. The ADMS will interface with the supervisory control to manage any problems with overproduction of solar. Short circuit current should be managed actively with the power electronic inverters and Petersen coils if allowable by utility policy. However, distribution automation may be an expensive investment for a single microgrid, so costs and resilience benefits will be weighed carefully.

Microgrid power control is usefully categorized into three hierarchical levels:

1. Primary control: voltage and frequency values and stability, on the order of milliseconds
2. Secondary control: active and reactive power control, on the order of seconds
3. Tertiary or supervisory control: energy balance and economic dispatch from all DERs, on the order of minutes

Primary V/f control will be achieved by power electronic inverters, injecting current from a DC bus of both solar and storage assets or just storage. Voltage and frequency allowable ranges will be the same NEC standard for grid interactive DER inverters, while settings like short circuit current and fault ride through will be decided by the technical study. Secondary power control will be similarly achieved at the inverter level.

Tertiary control is primarily economic, although for a resilient microgrid the currency is hours of operation not dollars. In islanded microgrid mode, a central controller will perform day ahead load and solar forecasts and solve the unit commitment problem (optimize the dispatch of all DERs) with full information of DER capabilities like battery state of charge and fuel tank levels. In grid-connected mode the controller will minimize the utility electric bill to the tribe based on solar self-consumption, peak shaving, and demand response and other ancillary services if available. For this the microgrid will likely need to be OpenADR compatible. The controller will monitor weather and storm alert warnings through cloud APIs to prepare the microgrid for a possible grid outage.

The assumption is that control will be centralized with communication links to other devices. However, a peer-to-peer network is a possibility. The advantages of a central controller are a simpler star-network and excellent dispatch optimization. However, there are disadvantages, such as a single point of failure and a controller that must always know exactly the energy resources available and topology of the microgrid. This mostly precludes, for instance, a self-healing microgrid that can automatically isolate a downed line. It also prevents quick "plug-and-play" additions to the microgrid, such as a generator on a trailer or new vehicle-to-grid EVs.

Peer-to-peer control solves most of these problems, at the cost of complexity and somewhat less optimized dispatch. The technology certainly deserves investigation, and there are realistic equipment choices, for instance using S&C Electric's GridMaster controller.

Islanding

Islanding is the most difficult task for a microgrid design and operation. A POC and automatic isolation switch must be identified which comply with utility policy. Especially on the medium voltage network, detecting a grid outage is not always straightforward considering ride through requirements and certain phenomena on the high voltage network can cause the switch to mistakenly open. Engineers must carefully program the re-connection settings to not accidentally power the utility grid and put workers at risk, especially if the microgrid is part of a black start program. Lastly, the islanded microgrid must be stable at every level of the control hierarchy and handle faults gracefully.

The Bad River community microgrid POC location will be chosen for reliable operation, possibly at the cost of needing new lines. The Advanced Distribution Management System (ADMS) will then need to notify protection systems for the likely change in reclosing algorithm. The supervisory controller will need to change the dispatch algorithm and maybe activate new DERs. The handover should be nearly seamless from the point of view of loads, although several 60 Hz cycles of poor power quality are likely tolerable. A summary of system sizing analysis can be found in Table 6, Appendix F.

3.4.9. Financial Analysis

Cost Reduction

On the 6LP rate structure, the tribe pays Bayfield Electric \$0.10/kWh for energy and \$12.1/kW for monthly demand, resulting in a blended rate of about \$0.135/kWh. In 2020 after a competitive bid process the tribe energy team chose EnTech Solutions to build and operate the three building microgrids, and signed an Energy Services Agreement (ESA) to buy energy at \$0.107/kWh with no demand charge. That 21% discount is substantial especially considering the value the tribe receives from having clean and resilient generation sources on the reservation. The ESA involved a third-party ownership structure, but in very rough terms a similar target price on clean and resilient energy is reasonable. The feasibility study will include this path to a similar energy cost reduction:

1. High level economic modelling of the microgrid capex and operating expenditures (opex) over a reasonable equipment lifetime
2. Inclusion of grants, the investment tax credit (ITC), and modified accelerated cost recovery program system (MACRS)
3. Careful optimization of the community microgrid design to avoid surprise construction or maintenance costs
4. Competitive bid process with specified DER sizes and suggested equipment choices to de-risk the project for bidders

5. Efficient dispatch algorithm and value stacking to maximize microgrid revenue from all sources possible: solar self-consumption, peak shaving (bill demand reduction), consumption time-shifting if applicable, demand response or other ancillary services

Analysis Approach

muGrid Analytics will perform the economic and financial analysis using an annualized cash flow *pro forma* approach and projected revenues and costs. Solar production is modelled in Helioscope with irradiance data from Ironwood, MI, and muGrid proprietary modelling software simulates the microgrid in grid-connected and islanded modes. Annual revenues from utility bill savings are the sum of energy savings due to self-generation and consumption, time-shifting based on time of use (TOU) periods, and peak shaving. Demand response or other ancillary services may be a direct payment or bill credit. DER and equipment initial and expected replacement capex are estimated from muGrid cost models, including the ITC and MACRS. A cost model for the distribution lines, transformers, and protection equipment will be developed. Opex will include normal maintenance of DERs and distribution infrastructure, taxes, insurance, and any service fees. An energy and demand rate escalator will increase each separately. Net cash flow can then be calculated to show the financial performance each year, as well as summary economic metrics like IRR, NPV, and SPP. Table 5 in Appendix F summarizes the most important financial modelling assumptions which can be estimated now, although they may be fine-tuned especially for large changes in DER scale or technology.

Local Economic Stimulus

Cheq Bay Renewables, Madison Solar Consulting, Faith Technologies (owner of EnTech Solutions), both utility cooperatives, and Power Systems Engineering are all Wisconsin companies. The tribal energy team also has a working relationship with local electrical contractor Jolma Electric who employs 15 full time employees at excellent compensation. Many DER projects and buildings have minimal operating expenses and therefore don't support local companies over time after construction, but maintenance of distribution systems (if owned by the tribe) will require more annual labor and materials. Solar modules, CHP equipment, power electronics, and grid equipment can often be sourced from US manufacturing, whereas battery storage cells almost entirely originate from abroad. The tribe also has a DER jobs training program to train tribal members in anticipation of full ownership of current microgrid systems starting at year seven. The community microgrid would easily integrate and expand employment opportunities.

3.4.10. Environmental Impact.

For the community microgrid the tribe is considering only low-emission new DERs and the existing natural gas and diesel generators are seldomly run. The asset capacities are not yet known, but to achieve the resilience objective at minimal cost the HWC and WWTP building microgrid solar plants are sized to 96% and 137% of the load on an annual energy basis, respectively. This matches muGrid's experience which is that often the solar plant is sized greater than net zero to meet a resilience goal in the 1-2 week range at very high confidence. With several buildings on a community microgrid there will be some aggregation of load, so the peaks should be lower and perhaps a slightly smaller solar plant is required as a percentage of cumulative annual load. Bad River has used the EPA Greenhouse Gas Equivalencies Calculator to showcase environmental benefits of its existing microgrids and will update those benefits once the new microgrid's components are sized. An example of the existing building microgrids' lifetime emissions relative to baseline are included in Appendix E.

Technology selection is also discussed in *Technologies Under Consideration* but more depth on the environmental aspects follows:

- Solar PV is attractive because of its extensive environmental benefit documentation. The longevity of solar modules and recyclability of the modules and racking components is well documented[7].
- Lithium-ion batteries, albeit more controversial in terms of recycling vs. steel, aluminum or glass, is coming of age as more recycling centers are becoming available.[8] Other technologies were considered in current and past studies.
- Biogas was studied in 2014 and was rejected by the tribe because of economic as well as air quality concerns.
- Wind was studied in 2007 and rejected for economic, resource availability and maintenance concerns. Hydrogen production is an up-and-coming technology that the tribe is analyzing and could match well with existing and future microgrids as technology improves and costs come down.

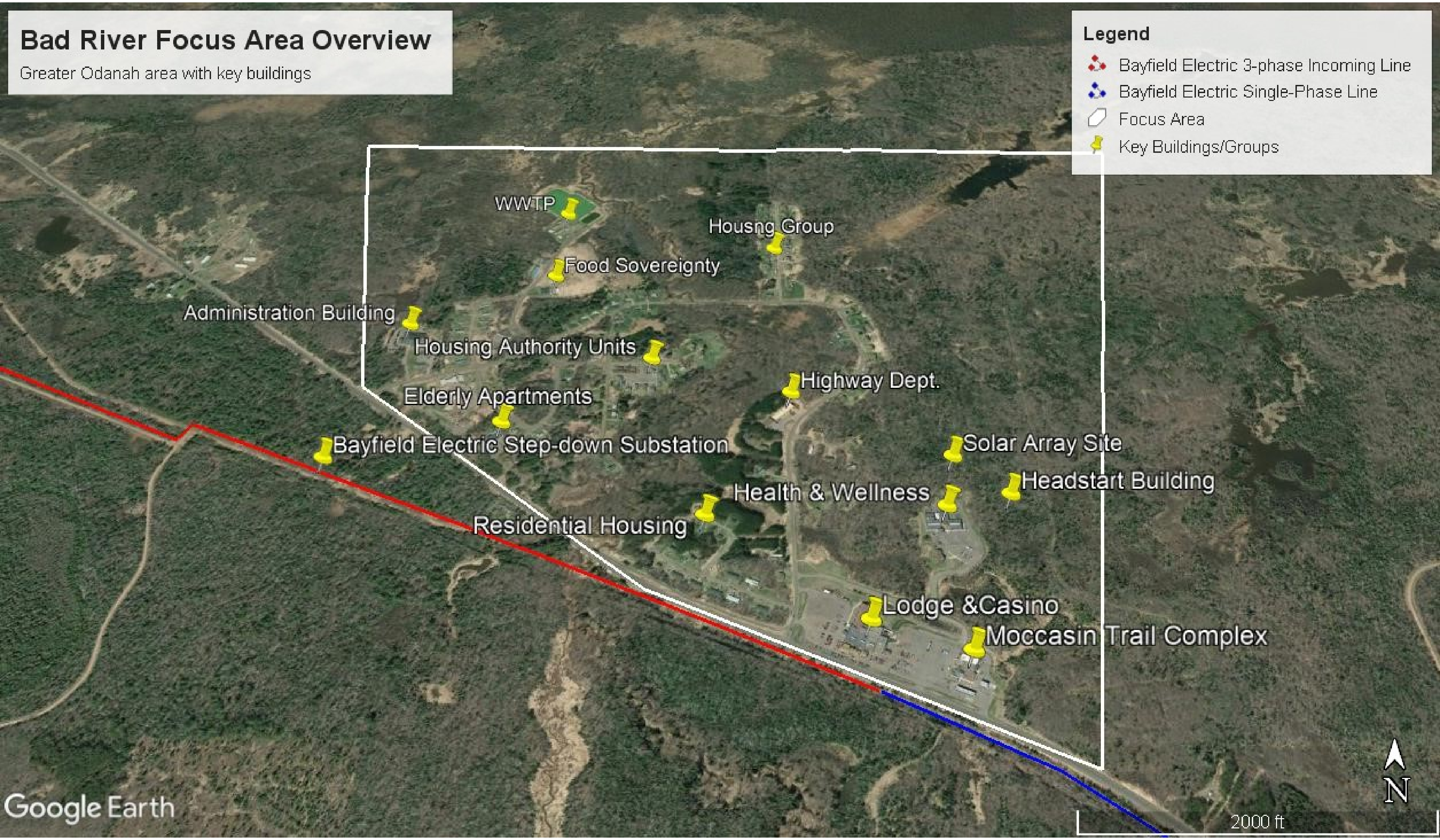
DER technology selection follows a methodology of (a) study, (b) pilot, and (c) review. So far only solar and storage have surpassed the study phase because of concerns mentioned above regarding emissions, feedstock, and groundwater pollution. Solar and storage will complete the review phase at the one-year after commissioning mark, when muGrid Analytics will have completed a Monitoring and Validation contract and will report on the three building microgrids' economic, resilience, and emissions performance.

Reference Materials

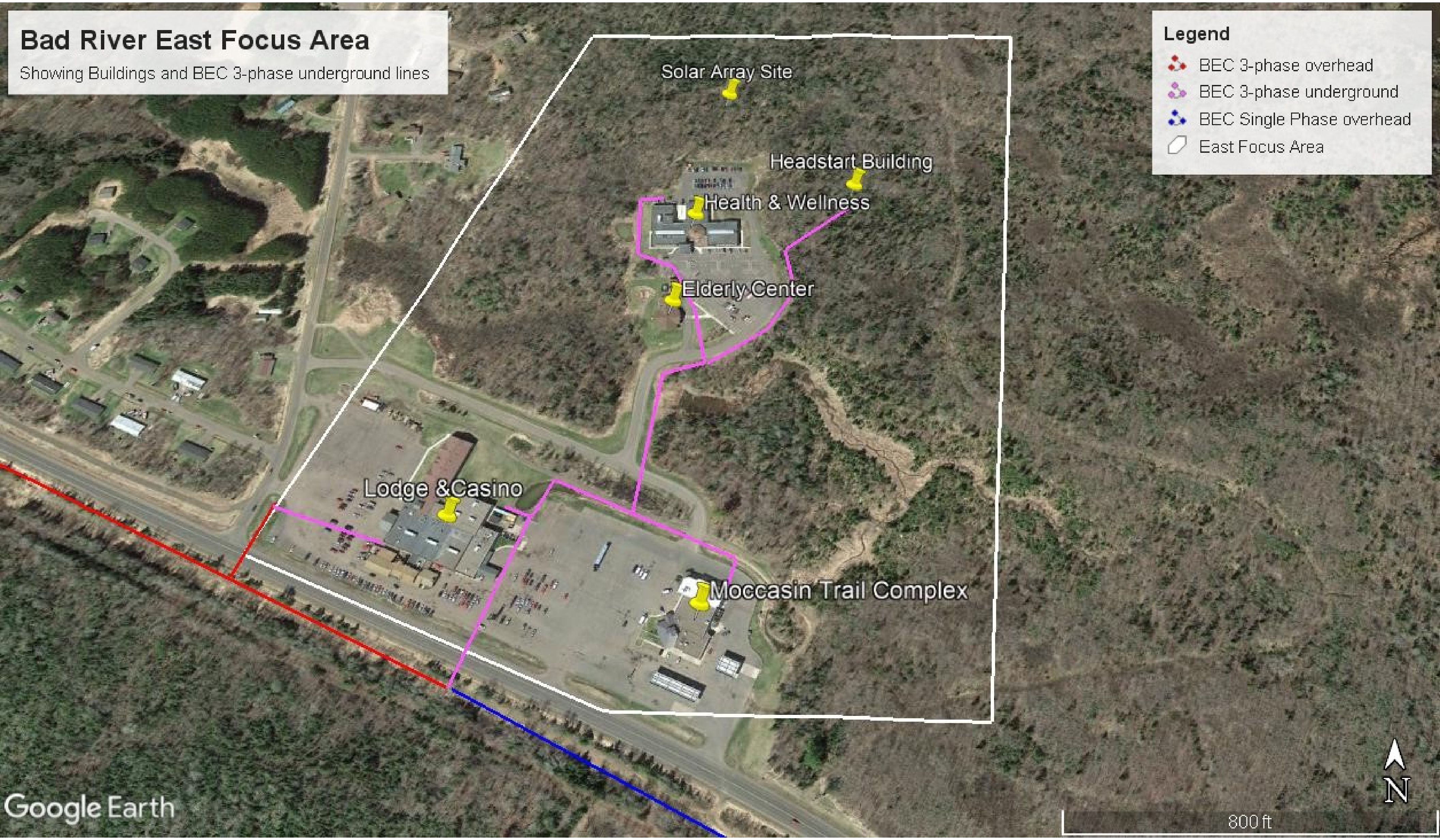
Appendix A: Site Maps
Appendix B: Letters of Support
Appendix C: muGrid and Madison Solar Consulting SOW
Appendix D: Sample Resiliency Heat Maps
Appendix E: EPA Calculations results for Health & Wellness Center (example)
Appendix F: Tables

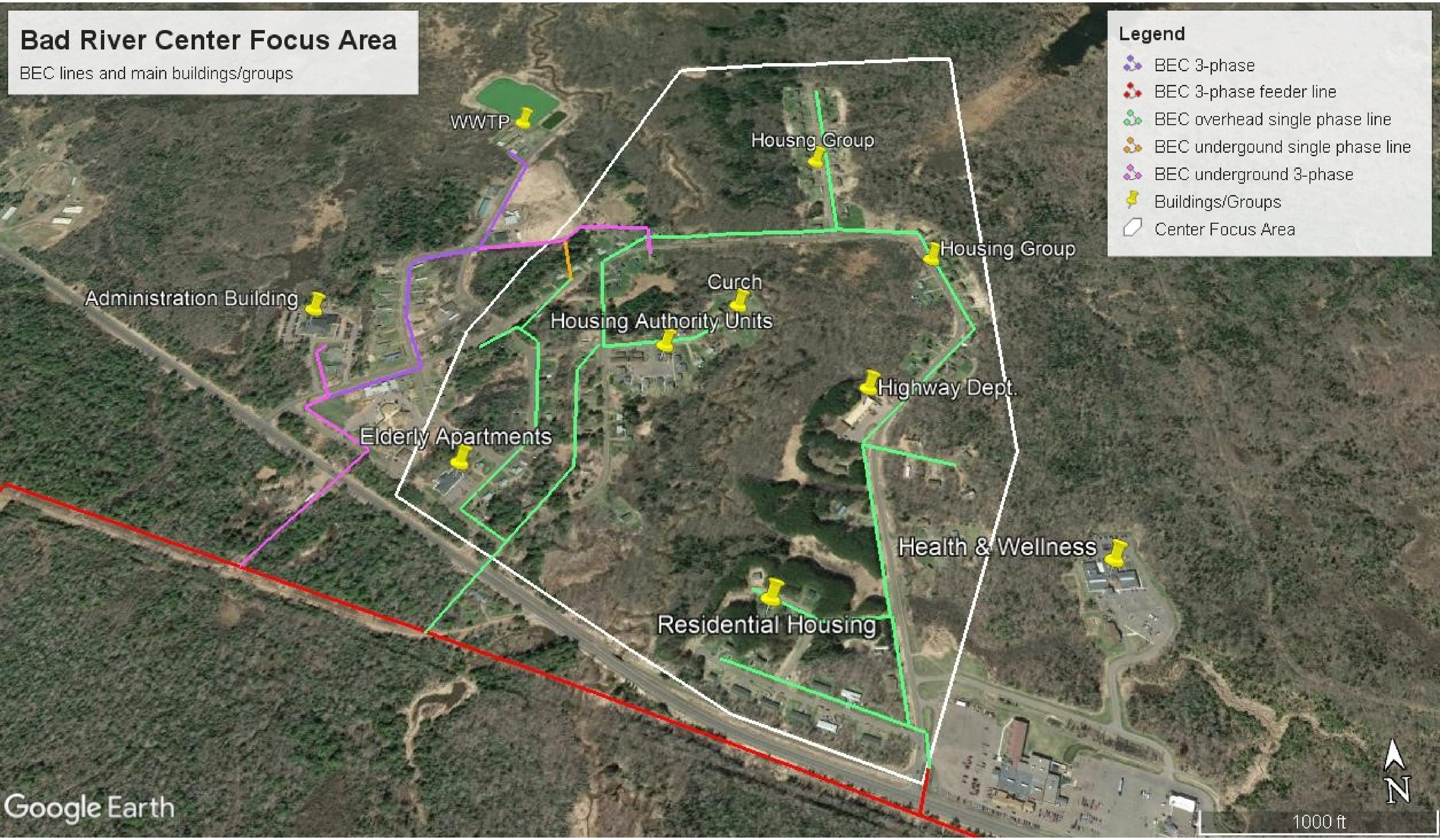
[7] [Are Solar Panels Recyclable? Here's How to Recycle Them (greenmatters.com)]()

[8] EnergyPort, manufacturer of the batteries for the existing microgrids has been contacted but we have not received a reply on recommended procedures or other documentation

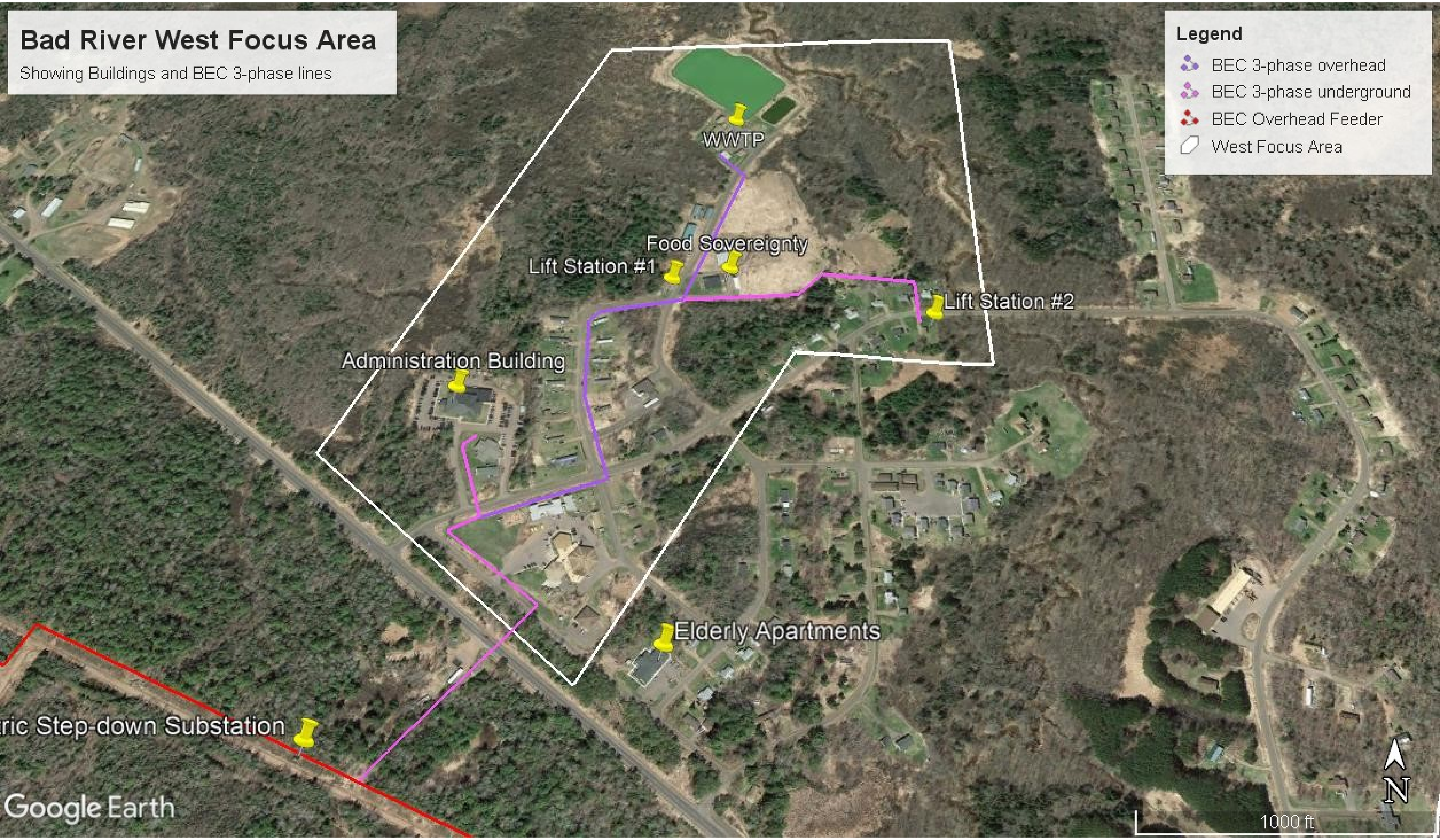


Bad River Focus Area Overview
Greater Odanah area with key buildings
Legend
Bayfield Electric 3-phase Incoming Line
Bayfield Electric Single-Phase Line
Focus Area
Key Buildings/Groups
WWTP
Housng Group
Food Sovereignty
Administration Building
Housing Authority Units
Highway Dept.
Elderly Apartments
Bayfield Electric Step-down Substation
Solar Array Site
Headstart Building
Health & Wellness
Residential Housing
Lodge &Casino
Moccasin Trail Complex
Google Earth
N
2000 ft

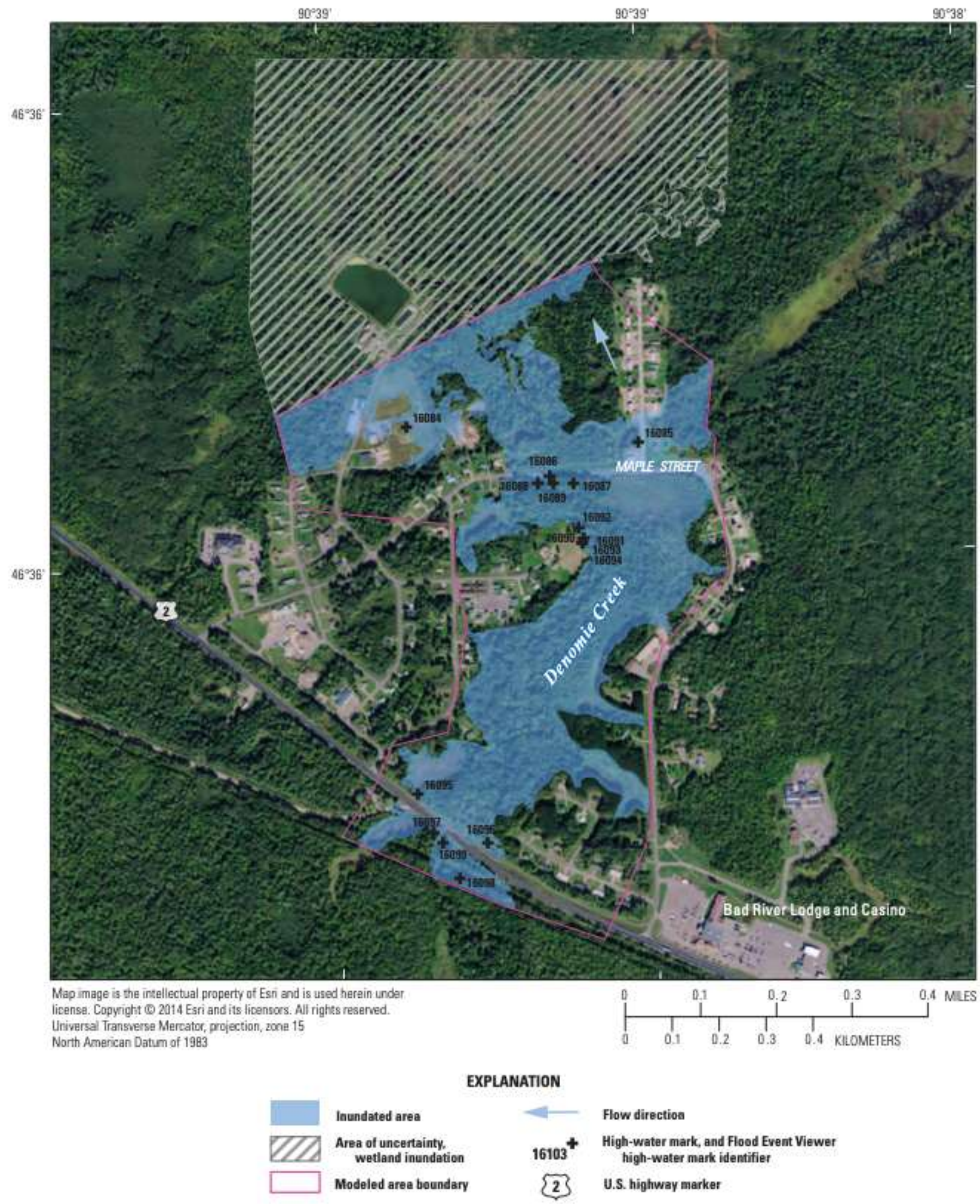

Bad River East Focus Area
Showing Buildings and BEC 3-phase underground lines
Legend
BEC 3-phase overhead
BEC 3-phase underground
BEC Single Phase overhead
East Focus Area
Solar Array Site
Headstart Building
Health & Wellness
Elderly Center
Lodge &Casino
Moccasin Trail Complex
Google Earth
800 ft
N



Bad River Center Focus Area
BEC lines and main buildings/groups
Legend
BEC 3-phase
BEC 3-phase feeder line
BEC overhead single phase line
BEC undergound single phase line
BEC underground 3-phase
Buildings/Groups
Center Focus Area
WWTP
Housng Group
Housing Group
Curch
Administration Building
Housing Authority Units
Highway Dept.
Elderly Apartments
Health & Wellness
Residential Housing
Google Earth
N
1000 ft


Bad River West Focus Area
Showing Buildings and BEC 3-phase lines
Legend
BEC 3-phase overhead
BEC 3-phase underground
BEC Overhead Feeder
West Focus Area
WWTP
Food Sovereignty
Lift Station #1
Lift Station #2
Administration Building
Elderly Apartments
ric Step-down Substation
Google Earth
1000 ft
N

2016 Flood Map in Odanah, WI



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Phone (715) 372-4287 • Fax (715) 372-4318

August 3, 2021

Public Service Commission of Wisconsin
Office of Energy Innovation

Subject: Letter of Support – Critical Infrastructure Microgrid & Community Resilience Center Pilot Grant Program

Dear Office of Energy Innovation:

On behalf of Bayfield Electric Cooperative ("BEC"), we are pleased to submit this Letter of Support for the Bad River Band of Lake Superior Tribe of Chippewa Indians ("Tribe") application for the Office of Energy Innovation's Critical Infrastructure Microgrid & Community Resilience Center Resilience Center Pilot Grant.

BEC currently serves the area which is the focus of the grant. Additionally, most Tribal members are also BEC members. The Tribe is building a future of clean and resilient energy via a renewable energy microgrid. The Tribe's 2020 Long Range Energy Plan identifies tribal values, the most feasible technology options, and a phased approach.

BEC has met with Tribal leadership and discussed mutually beneficial ways to work towards Tribe's strategic energy goals. BEC supports the Tribe on the development and execution of the Mashkiiziibii Community Resilient Microgrid Study Project. However, many economic, technical, and operational questions remain as BEC and the Tribe moves forward. BEC supports and will work with the Tribe to achieve its goals addressed in this grant application.

If there are any questions on this letter of support, please feel free to contact me at (715) 372-7527 or christopher.kopel@bayfieldelectric.com. Thank you for your consideration and approval of this application.

Sincerely,

Christopher Kopel
Chief Executive Officer

Cheq Bay Renewables

To: Public Service Commission of Wisconsin- Office of Energy Innovation **Date: August 4, 2021**
From: William Bailey, President, Cheq Bay Renewables
RE: OEI- Critical Infrastructure Microgrid & Community Resilience Center Pilot Grant Program:
Cheq Bay Renewables Support Letter

Over the past three years, Cheq Bay Renewables (CBR) has watched the Bad River Tribe go from nearly no renewable energy to three state-of-the-art microgrids collectively containing the largest battery storage system in Wisconsin. It reminds me of Africa; they skipped 80 years of land lines and went right to cell towers and cell phones.

Now, they have the wherewithal to realize if they want to further reduce their carbon footprint (they do) and increase long-term goals of resiliency for all, another leap is necessary. The reservation is fed by a nearly 15-mile-long radial electric line that has nearly reached its capacity to house more renewable generation. The umbilical cord is vulnerable and the population it serves is disadvantaged. Without a thorough examination of the technical and economic implications of addressing this problem, money could easily be misappropriated or wasted chasing after an elusive target.

muGrid Analytics excels in techno-economic analysis. In fact, before I met Travis and Amy Simpkins, I had never heard of techno-economic analysis, because I think they may have coined the term. Modeling electric flow in real-time, running multiple scenarios to determine optimal component capacities, developing dispatch algorithms to maximize resilience coupled with economic benefit, confirming interoperability of system controls; that's what they do.

But, if that isn't enough, a third component is needed to successfully create a community-wide resilient microgrid. It involves looking at utility policy and regulation, infrastructure ownership, contractual arrangements and public safety. The lines blur when customers of a utility are actually members, and therefore owners, of the utility. The only way forward is cooperation between the utility and the member. Bayfield Electric Cooperative has a new CEO who is ready to engage with the tribe, to chart a 21-century utility where we all breath the same air. Madison Solar Consulting and Cheq Bay Renewables are equally engaged to assist the tribe in charting this new course.

The tribe wants to take the next leap, a community-wide resiliency center, but first they must examine through a techno-economic-cooperative analysis (TEC) what their options are, what Bayfield Electric Cooperative's options are, and what the best outcome might be for all involved.

I encourage the Public Service Commission of Wisconsin- Office of Energy Innovation to support this unique opportunity to explore what a 21^{st} century utility partnership should become.

William (Bill) Bailey

William Bailey

www.CheqBayRenewables.org

To: Public Service Commission of Wisconsin- Office of Energy Innovation

From: Dan Nordloh, Senior VP & GM Distributed Energy

RE: OEI- Critical Infrastructure Microgrid & Community Resilience Center Pilot Grant Program: Entech Support Letter

Date: **August 3, 2021**

The Bad River Band of Lake Superior Tribe of Chippewa Indians is applying for a project under the Public Service Commission of Wisconsin, specifically within the Office of Energy Innovation's Critical Infrastructure Microgrid & Community Resilience Center Resilience Center Pilot Grant.

The Bad River Tribe is building a future of clean and resilient energy via a renewable energy microgrid. The 2020 Long Range Energy Plan identifies tribal values and the most feasible technology options, and proposes a phased approach. Recently in 2021 the first phase, also named the Ishkonige Nawadide Microgrid Project was commissioned, as a crucial technology pilots using solar and storage. Now a thorough techno-economic study is required to highlight a feasible path to a tribal minigrid, given the Project Teams identification of gaps and operational constraints of managing rural electric distribution.

Entech assisted the Tribe with the execution and the installation of the Ishkonige Nawadide Microgrid project and supports the Tribe's strategic energy goals. Entech supports the Tribe on the development and execution of the Mashkiiziibii Community Resilient Minigrid Study Project that aims to address the Tribal goals and that will be submitted under the Office of Energy Innovation's Critical Infrastructure Microgrid & Community Resilience Center Resilience Center Pilot Grant.

If there are any questions on this letter of support toward this project, please feel free to contact me at Dan.Nordloh@energybyentech.com.

Thank you,

DocuSigned by:

DANIEL NORDLOH

2DDAF4326B29438...

Dan Nordloh

8/3/2021

August 3, 2021

Mr. Dan Wiggins, Jr., Renewable Energy Coordinator
Bad River Tribal Government Offices - Chief Blackbird Center
72632 Maple Street
Odanah, WI 54861

Dear Daniel,

As the Bad River Tribe pursues OEI microgrid expansion feasibility study funding, Madison Solar Consulting would very much enjoy supporting the Tribe with this effort.

Project Name: Bad River - Microgrid Expansion Feasibility Study

Scope of Work:

1. Attending team calls and meetings, and keeping abreast of the project's development to help guide the study by contributing my experience working in Wisconsin on PV and battery projects, particularly concerning Wisconsin-specific policy issues
2. Leading the policy portions of the feasibility study and author the policy-related sections of the feasibility study
3. Reviewing, editing, and commenting on the project's deliverables including presentations, project reporting, and the feasibility study
4. Supporting the Project Manager as needed. This would include supporting his presentations to the Tribal Council, OEI and others
5. Supporting with muGrid, with the project's techno-economic analysis, through discussions and review

Level of Effort

Task	Hours
1. Stay current with the study and participating in team meetings	34
2. Leading policy efforts	34
3. Writing, reviewing, and editing project deliverables	8
4. Supporting the Project Manager	4
5. Supporting muGrid	4
Total	84
In-kind hours	18
Billed hours	66

Budget: Billing at $110/hour for a maximum of 66 billed hours, for a budget of $7,260

Terms and Conditions:

1. Net Payment due in 30 days from receipt of invoice
2. No travel is expected. Should it be required, it will be billed to Bad River and reimbursed at actual and reasonable cost.

Sincerely,

Rich R. Wolters

Niels R. Wolter
Madison Solar Consulting

Cc: *William Bailey, Chequamegon Bay Renewables*

Bad River Microgrid Project – Wisconsin Critical Infrastructure Microgrid & Community Resilience Center Pilot Grant Program Application 2021

muGrid Analytics Proposed Scope of Work and Budget, 8/6/2021

Background

The Bad River Band of the Lake Superior Chippewa is building a clean and resilient future with an advanced renewable energy community microgrid. The band, or tribe, is comprised of 1,643 members on the 124,655 acre Bad River Reservation of mostly undeveloped wilderness, which the community depends on for hunting, fishing, and gathering rights since the *Treaty of 1854*. In 2016 a five-hundred-year-flood took two lives, halted electric, natural gas and roadways for weeks, and caused over $25M in damage. Since then a series of disaster mitigation and response plans have been completed, which identify resilience objectives and protocols. More recently the tribe identified a phased path towards its clean and resilient energy goals in a *Long Range Energy Planning Report*. In 2021 the tribal energy team and partners commissioned the first tribal advanced building microgrids: the Health and Wellness Center, Chief Blackhawk administration building, and Waste Water Treatment Plant. These simultaneous technology pilots are evidence of the team's capacity to plan and execute complex energy projects. Now a thorough techno-economic study is required to find a feasible path to the larger community microgrid that meets the tribe's clean resilience objectives, given the learnings of the pilot projects. An experienced team comprising of muGrid Analytics, Cheq Bay Renewables, and Madison Solar Consulting are well prepared to support the tribe on this project, as with the previous successful microgrids.

Project Description

The goal of this phase is to understand the technical requirements of a tribal renewable energy microgrid and approximate the financial implications.

The study objectives are:

1. *Coordination*: since operating a community microgrid is a large responsibility with significant risk, the study should work closely with tribal staff and leaders especially during discussions of specific resilience, economic, and emissions objectives

2. *Load Estimation*: accurately estimate the electrical load since this is a major driver of project cost
3. *Generation Adequacy*: optimally sized generation and storage assets to serve the load at minimum cost
4. *Distribution Network*: microgrid topologies that serve the Community Resilience Centers, and an interconnection(s) that island the microgrid
5. *Microgrid Operation*: safe, secure, and economic dispatch of generation, fault handling, and load control if implemented
6. *Business and Policy*: evaluate the financial and operational responsibilities that will be incumbent on the tribe
7. *Reporting*: present the rigorously tested findings in a clear and concise way

Deliverables

The feasibility study will deliver both (a) actionable recommendations and a (b) rich body of knowledge to facilitate future design excursions. The deliverables are:

1. *Report:* a comprehensive but concise report of the study assumptions, methodologies, findings, and recommendations (no less than 50 pages)
2. *Microgrid Design*: technical drawings and report sections identifying the most economic distributed energy assets, microgrid topology and interconnection(s), operational tools, and equipment selection – including a single top recommendation given the tribe's objectives
3. *Database*: all load and modelled solar data with instructions and labels
4. *Financial Models*: pro forma and costing tools for future design excursions
5. *Metering*: access and instructions will be provided for the eGauge load meters

Budget

The project will be billed actual hours according to the rate schedule below:

Work Type	**Hourly Rate**
Principal Consultant	$225
Engineer	$150
Analyst	$60

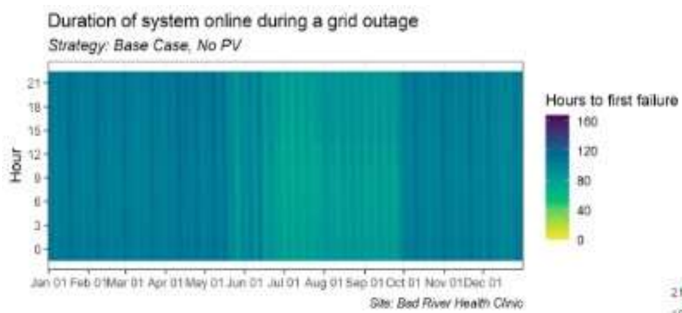
muGrid will be pleased to contribute 15 hours of Principal Consultant time as an in-kind contribution to the project and cost share.

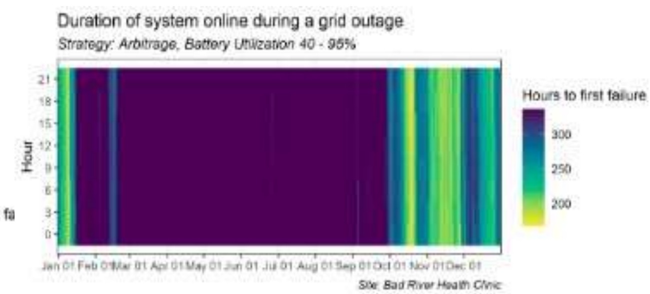
The Work Breakdown for each task is expected as follows (next page):

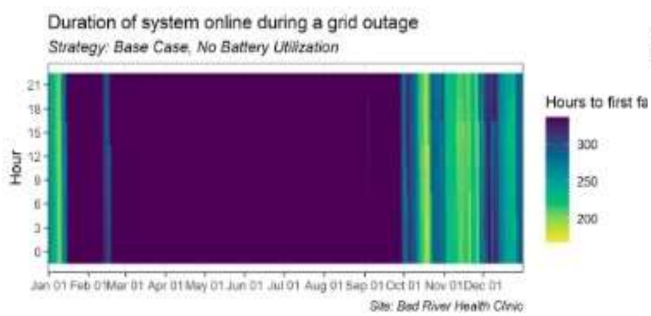
	Task	Principal h	Engineering h	Analyst h	Equipment	Trips
	Rate ($ per)	*225*	*150*	*60*	*1200*	*900*
Load Estimation	Acquire feeder and meter data from Bayfield Electric			18		
	Install (labor in-kind from Cheq Bay Renewables) and validate egauge load meters			16	8	
	Estimation of missing load data using machine learning techniques	10	50	15		
	Forecast of 25-year load growth	10	15	5		
	Subtotals	$ 4,500	$ 9,750	$ 3,240	$ 9,600	$ -
Generation Adequacy	Perform first techno-economic analysis of required generation and storage capacities to serve (a) the entire load or (b) some percentage of the load, assuming an interconnection with Bayfield Electric Co-op	15	10	10		
	Choose initial generation and storage asset locations based on economics	10	10			
	Subtotals	$ 5,625	$ 3,000	$ 600	$ -	$ -
Distribution Network and Microgrid Operation	Mapping and identification of existing Bayfield Electric Co-op lines and transformers on tribal land		5	20		1
	Model distribution system in software	5	30			
	Perform quasi-dynamic steady state analysis to understand worst case voltage profile of each line	5	15	10		
	Calculate short circuit currents, develop protection strategy based on commercial offerings	5	30	10		
	Develop control and dispatch strategy considering existing microgrid equipment	30	60			
	Subtotals	$ 10,125	$ 21,000	$ 2,400	$ -	$ 900
Business and Policy	Analysis of ownership or operation options of existing lines and transformers	2	10			
	Metering analysis including automatic metering	2	10			
	Analysis of possible billing, rate design, and customer policy	10	5			
	Approximate the equipment replacement schedule		10			
	Analysis of interconnection options with Bayfield Electric Co-op	5	10			
	Subtotals	$ 4,275	$ 6,750	$ -	$ -	$ -
Reporting	Iterate on generation and storage asset locations and control and protection strategy to minimize cost to the tribe while providing a menu of options	5	15	15		1
	Report writing	15	20	20		
	Subtotals	$ 4,500	$ 5,250	$ 2,100	$ -	$ 900
	In kind contribution / cost share	-15				
	Totals	$ 25,650	$ 45,750	$ 8,340	$ 9,600	$1,800
	TOTAL PROJECT BUDGET	$ 91,140				

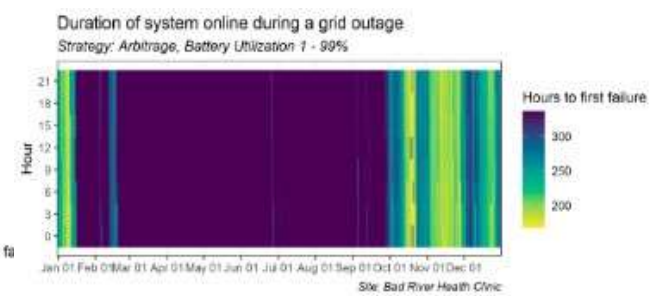
Appendix D – Sample Resiliency Heat Maps for Bad River Health & Wellness Center

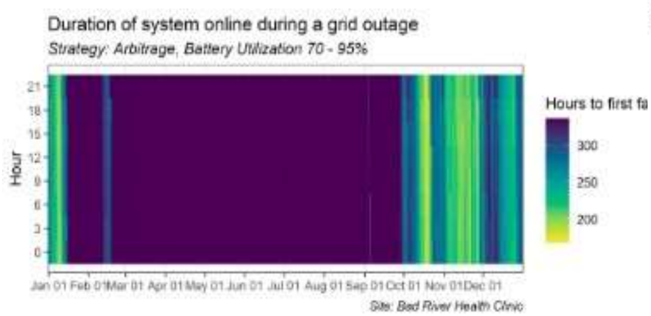
The following heat maps are from a resiliency analysis completed by muGrid Analytics for the Bad River Health & Wellness Center. They show the anticipated time-to-first-failure (TTFF) of the solar-battery-generator microgrid for outages starting at every hour of the year. The hours of the day are on the vertical axis, while the months of the year are on the horizontal axis. Darker, purple colors represent longer outage durations, 6 days and longer. The lighter blue colors provide support for around 3-4 days. Five scenarios are shown below with varying strategies of battery utilization. These maps support the idea that nearly full battery utilization does not significantly affect TTFF.











muGrid Analytics

Appendix E – EPA Equivalency for the Bad River Health & Wellness Center

These equivalencies are based on the annual generation of 300kW DC of solar PV:

Equivalency Results

[How are they calculated?]

The sum of the greenhouse gas emissions you entered above is of Carbon Dioxide Equivalent. This is equivalent to:

283 Tons

Greenhouse gas emissions from

55.8 Passenger vehicles driven for one year

-or-

644,743 Miles driven by an average passenger vehicle

CO_2 emissions from

28,867 gallons of gasoline consumed

-or-

25,201 gallons of diesel consumed

-or-

283,553 Pounds of coal burned

-or-

3.4 tanker trucks' worth of gasoline

-or-

	homes' energy use for one year	*-or-*		homes' electricity use for one year	*-or-*

1.4

railcars' worth of coal burned

-or-

594

barrels of oil consumed

-or-

10,487

propane cylinders used for home barbeques

-or-

0.0001

coal-fired power plants in one year

-or-

31,206,576

number of smartphones charged

Greenhouse gas emissions avoided by

87.3

Tons of waste recycled instead of landfilled

-or-

12.5

Garbage trucks of waste recycled instead of landfilled

-or-

10,916

0.053

trash bags of waste recycled instead of landfilled

-or-

Wind turbines running for a year

-or-

9,723

Incandescent lamps switched to LEDs

Carbon sequestered by

4,242

tree seedlings grown for 10 years

-or-

314

acres of U.S. forests in one year

-or-

1.8

acres of U.S. forests preserved from conversion to cropland in one year

Appendix F Tables

Table 1: Key Partners and Stakeholders

Partners	Role	Responsibility
Bad River Tribe – Department of Natural Resources, Renewable Energy	Project manager	Oversite and project control, liaison to Tribal Council
muGrid Analytics	Microgrid techno-economic consultant	All engineering and technical aspects of study
Cheq Bay Renewables	Management, financial support	Assist is project coordination, scheduling and financial overview
Madison Solar Consulting	Project development, solar PV modeling	Policy overview, technical support
Bayfield Electric Cooperative	Local distribution utility	Code compliance, public safety, technical assistance
EnTech Solutions (not Entech Energy Services, Entech Renewable Energy Solutions, or Entech Energy Services)	Microgrid final engineering, construction, and operation	Respond to technical information requests about interoperability of existing equipment

Table 2: Hazards and Energy-related Resilient Objectives

Hazard	**Probability**	**Impact**	**Energy-Related Resilient Objectives**	**Notes**
All			*life support systems, first aid, communication, lighting, transportation*	
Flooding	High	High	shelters, pumping	history of bad flooding, as recent as 2016 ($25 million in damages)
Winter storms	High	High	shelters, snow clearing	climate change may cause more ice than snow in the future
Wildfires	Low	High	shelters, water main pressure (Odanah)	85% of reservation land area is forest
Lightning and wind storms	Med	Med		frequent in summer, related to flooding
Extreme cold	Med	Med	shelters (warming)	
Extreme heat	Med	Med	shelters (cooling)	

Table 3: Building Constraints and Opportunities

Building	Description	Constraints	Opportunities
Health and Wellness Center (clinic)	Medical and dental clinics, vision care, pharmacy, lab, x-rays, community room, medical refrigeration, 25,000 sq. ft., built in 2010	Limited critical care capacity, likely expansion	Existing solar+storage and diesel microgrid, space for new solar, medical equipment, designated shelter, likely expansion, three phase, load data
Bad River Lodge and Casino	Gaming floor, restaurant, 50 rooms, pool and jacuzzi, ample paved parking	Significant but finite rooftop solar space, likely inadequate main load center amperage, no load data	Commercial kitchen, large parking lot for solar carports, beds, mini-refrigerators, designated shelter, 3 phase
Elderly building	Commercial kitchen, large common room, 4,187 sq. ft.	Likely inadequate main load center amperage, no load data	Three-phase, large common room, proximity to clinic microgrid
Chief Blackbird administration building	Offices, conference rooms, labs, courtroom, commercial kitchen	Limited open space for shelter	Emergency command center, communication equipment, existing small solar+storage microgrid, designated shelter, three phase, load data
Head Start Center (preschool)	Preschool with classrooms, play rooms, library, shower, 2020 construction, 13,200 sq. ft.		Existing solar, kitchen, close to clinic, backup line gas generator and small solar array, three phase, designated space for new solar, load data

Table 4: Emissions and Levelized Cost of Electricity

	Solar PV	Battery Storage	Biomass CHP	Natural Gas ICE Generator	Diesel ICE Generator
Median lifecycle emissions (gCO2 eq / kWh produced)	44	--	40 (highly variable based on specific technology)	979	1625
Median lifecycle emissions (gCO2 eq / kWh installed)	--	630	--	--	--
Unsubsidized levelized cost of electricity (LCOE) generation ($/MWh)	74 - 179	--	55 - 114	68 - 106	197 - 281

Unsubsidized levelized cost of storage (LCOS) ($/MWh)	--	432-590	--	--	--
Operation and maintenance assumptions	Replace inverters year 16 $44/kW	Replace 20% of cells year 6	Highly dependent on technology	Engine maintenance $4/kW/year	Engine maintenance $4/kW/year

References for table 4:

https://openei.org/apps/LCA/
https://www.researchgate.net/publication/311318990_CO2_Footprint_and_Life-Cycle_Costs_of_Electrochemical_Energy_Storage_for_Stationary_Grid_Applications
https://strathprints.strath.ac.uk/65068/1/Somorin_etal_RE2017_Life_cycle_assessment_of_self_generated_electricity_in_Nigeria.pdf
https://www.lazard.com/media/450337/lazard-levelized-cost-of-energy-version-110.pdf
https://www.lazard.com/media/451566/lazards-levelized-cost-of-storage-version-60-vf2.pdf

Table 5: Financial Modelling Assumptions:

Description	Rate or Value
Battery Capex	$600/kWh above 1 MWh
Battery Lifetime	10+ years
Battery Replacement	Need to replace cells depends on cycles, cost $300/kWh
Battery Annual Opex	$3/kW
Solar Capex	$1750/kW above 250 kWp
Solar Lifetime	25 years
Solar Inverter Replacement	$44/kW in year 16
Solar Annual Opex	$14/kW
Biomass	TBD
Discount Rate for NPV	4%

Table 6: Summary of System Sizing Analysis

Summary of System Sizing Analysis	
Project Cost Estimates	Will be estimated in feasibility study with load data
Critical Load Definition	100% of typical load
Backup Duration	Durable medical equipment and communication objectives: TTFF of one week (95% confidence) Heat, cooling, and refrigeration objectives: COT of one week (98% confidence)
Controls Strategy	Central V/f and power control from power electronic inverters, central supervisory controller with full information of all DERs, separate islanded and grid-

	connected dispatch optimizations, load and solar forecast, monitor storm warning bulletins, fully automatic microgrid distribution and protection
Islanding	Preferably single POC, automatic isolation switch operation carefully set with utility policy, near seamless handover and communication between switch, ADMS, and supervisory controller